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**STATIC STABILITY AND PRESSURE TEST  
OF A 0.04-SCALE MODEL  
OF THE APOLLO-SATURN V VEHICLE  
AT MACH NUMBERS FROM 0.60 THROUGH 1.40**



**T. O. Shadow and T. R. Brice  
ARO, Inc.**

**February 1968**

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*Per G. F. Keller  
Dated 4 April 73,  
Signed by  
William O. Cole.*

## FOREWORD

The work reported herein was done at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), for the Northrop Corporation under Program Area 921E and Project 9240.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The test was conducted under ARO Project No. PBI859 from November 7 to 10, 1967. The manuscript was submitted for publication on December 18, 1967.

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This technical report has been reviewed and is approved.

Richard W. Bradley  
Lt Colonel, USAF  
AF Representative, PWT  
Directorate of Test

Leonard T. Glaser  
Colonel, USAF  
Director of Test

## ABSTRACT

A 0.04-scale model of the Saturn V Missile was tested at transonic Mach numbers to determine Reynolds number effects on static stability characteristics and pressure distributions in the tail barrel region at high angles of attack. Reynolds number based on the model diameter varied from 0.9 to 8.4 million. Angle of attack was varied from -3 to 16 deg. The center of pressure varied with angle of attack over a distance of approximately one model diameter.

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## NOMENCLATURE

$A_b$	Area of the model base cross section, $1.89 \text{ ft}^2$
$C_A$	Total axial-force coefficient, $\frac{\text{measured axial force}}{q_\infty S}$
$C_{A,b}$	Base axial-force coefficient, $\frac{(p_\infty - p_b)}{q_\infty} \frac{A_b}{S}$
$C_{A,F}$	Forebody axial-force coefficient, $C_A - C_{A,b}$
$C_m$	Pitching-moment coefficient (see Fig. 3 for location of moment reference center), $\frac{\text{measured pitching moment}}{q_\infty S D}$
$C_N$	Normal-force coefficient, $\frac{\text{measured normal force}}{q_\infty S}$
$C_p$	Pressure coefficient, $\frac{p - p_\infty}{q_\infty}$

D	Model reference diameter, 1.320 ft
L	Model length, 13.819 ft
$\ell$	Longitudinal distance along the model measured from the nose of the escape rocket (Fig. 3), ft
$M_\infty$	Free-stream Mach number
$p_\infty$	Free-stream static pressure, psf
$p_{t_\infty}$	Free-stream total pressure, psf
$q_\infty$	Free-stream dynamic pressure, psf
Re	Reynolds number based on model diameter, $\frac{V_\infty D}{\nu_\infty}$
S	Model reference area, 1.368 ft <sup>2</sup>
$V_\infty$	Free-stream velocity, ft/sec
$x_{cp}$	Center-of-pressure location measured in reference diameters forward of the moment reference center, $C_m/C_N$
$x_{np}$	Neutral point location measured in reference diameters forward of the moment reference center, $dC_m/dC_N$ at $\alpha = 0$
$\alpha$	Angle of attack measured from the tunnel centerline, deg
$\nu_\infty$	Free-stream kinematic viscosity, ft <sup>2</sup> /sec
$\xi$	Longitudinal station measured along the shroud (Fig. 10), ft
$\phi$	Circumferential angle on shroud (Fig. 10), deg
$\psi$	Circumferential angle on model (Fig. 3), deg

## SECTION I INTRODUCTION

Force and pressure measurements were made on a 0.04-scale model of the Apollo-Saturn V Launch Vehicle in the Propulsion Wind Tunnel, Transonic (16T). The purpose of the test was to define the longitudinal static stability and axial force at high Reynolds numbers, and to obtain the pressure distribution in the shroud-fin region of the S-IC stage.

In order to achieve these objectives the model was tested at Mach numbers from 0.60 through 1.40 at Reynolds numbers from 0.9 to 8.4 million. The angle of attack was varied from -3 to 16 deg.

Results from a previous test in 16T, in which the pressure levels on the spacecraft and S-IVB stage were determined, may be found in Ref. 1. Force and pressure results from earlier tests at several facilities are presented in Ref. 2 for the model with Launch Escape System (LES), shrouds and fins, but devoid of other external protuberances.

## SECTION II APPARATUS

### 2.1 TEST FACILITY

Tunnel 16T is a variable density wind tunnel capable of operating from Mach number 0.55 to 1.60. The test section is 16 ft square and has perforated walls which allow continuous operation through the Mach number range with minimum wall interference. More details concerning the tunnel may be found in Ref. 3.

A sketch showing the Saturn V model in the 16T test section is presented in Fig. 1, Appendix I, and a photograph of the model in the tunnel is shown in Fig. 2.

### 2.2 MODEL

A sketch of the model is shown in Fig. 3. All significant external features of the full-scale vehicle, such as auxiliary propulsion units (APU), instrumentation tunnels, fins, and shrouds were simulated.

## 2.3 INSTRUMENTATION

### 2.3.1 Force and Moment Measurements

Six-component force and moment data were measured with an internally mounted, strain-gage balance. The balance signals were converted to digital form and routed to a computer where the force and moment coefficients were calculated. The base axial-force coefficient was determined by area weighting 38 pressures measured in the base plane region.

### 2.3.2 Pressure Measurements

All pressure orifices on the model were connected to 18 remotely controlled pneumatic switches with self-contained pressure transducers, each capable of measuring 48 pressures within a short time interval. The switches and transducers were mounted inside the model. The signals from the transducers were reduced to pressure coefficient form by the computer.

The model surface in the shroud-fin region was extensively instrumented with pressure orifices. Other orifices on the fins and shrouds (Fig. 4) brought the total number of model surface orifices to 739. Thirty-eight orifices in the base region increased the total pressures measured to 777.

## SECTION III TEST DESCRIPTION

### 3.1 PROCEDURE

The model was tested at three Reynolds number levels for Mach numbers from 0.60 through 1.40. The variation of Reynolds number based on the model reference diameter with Mach number is presented in Fig. 5.

At each Mach number and pressure the angle of attack was varied from -3 to 16 deg with force and pressure measurements made simultaneously. Force data were obtained at all angles of attack; however, pressure data were obtained at even-numbered angles only. The roll angle was zero, with the fins in the vertical and horizontal planes, for all cases.

## 3.2 PRECISION OF MEASUREMENTS

### 3.2.1 Tunnel Conditions

The uncertainties in setting and maintaining tunnel conditions are estimated to be as follows:

Mach number, subsonic	$\pm 0.005$
Mach number, supersonic	$\pm 0.010$
Total temperature	$\pm 5^{\circ}\text{F}$
Total pressure	$\pm 5$ psf

The longitudinal variation of Mach number along the tunnel center-line is not included in the above values, and reaches a maximum of  $\pm 0.007$  at supersonic Mach numbers.

### 3.2.2 Model Data

Values of maximum uncertainties for normal- and axial-force and pitching-moment coefficients are presented in Table I (Appendix II). The uncertainty in setting model angle of attack is  $\pm 0.1$  deg. The uncertainties associated with the model pressure measuring equipment are not accurately known; however, they are believed to be less than  $\pm 3$  psf for all cases.

All uncertainties in this section are based upon the assumption of a normal error distribution using a 95-percent confidence level.

## SECTION IV RESULTS AND DISCUSSION

### 4.1 FORCE PHASE

The variations of pitching-moment coefficient and normal-force coefficient with angle of attack are presented in Figs. 6 and 7, respectively. For the Mach numbers of the present test, the effect of varying the Reynolds number is seen to be small. The pitching-moment coefficient curves are linear to approximately  $\alpha = 5$  deg, and the normal-force coefficient curves are linear to higher values. The normal-force coefficients show generally good agreement with those of Ref. 2.

The variation of the center of pressure with angle of attack for the test Mach numbers is presented in Fig. 8. The center of pressure moved approximately one diameter forward as angle of attack increased

from 0 to 16 deg. The neutral point moved aft with increasing Mach number to 1.0 and then moved forward for supersonic Mach numbers. Total travel was approximately one diameter. The locations of the center of pressure and neutral point appear to be confined to a region bounded by a line slightly aft of the S-IC/S-II junction and the middle of the S-II stage (Fig. 3). These locations agree well with those presented in Ref. 2.

The forebody axial-force coefficients are shown in Fig. 9 as a function of angle of attack for the high Reynolds number level. Large, erratic variations in the axial-force coefficients occurred for the low and medium Reynolds number levels and were attributed to the high uncertainties as listed in Table I. Consequently, only the coefficients for the high Reynolds number level are presented. The values of  $C_{A,b}$  used in determining  $C_{A,F}$  were obtained by summing base axial-force coefficients for the model cavity, the model wall, and the four shrouds. Each of these component base axial-force coefficients was calculated from the average of the pressures measured at the base of that component.

## 4.2 PRESSURE PHASE

The longitudinal variation of pressure coefficients along a shroud using the nomenclature of Fig. 10 is presented in Fig. 11 for shroud meridian angles of 80, 50, and 20 deg. The pressure coefficients along the 20-deg meridian are disturbed to a greater extent by the base region than those along the other meridians. The dark symbols represent pressure coefficients along a ray approximately midway between two shrouds.

The effect of Reynolds number on the pressure coefficients of the region between the shrouds is shown in Fig. 12. The Reynolds number effect is small for most cases although differences at Mach number 1.20 are evident.

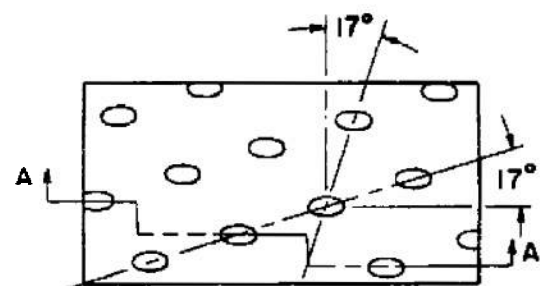
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1. Brice, T. R., Perkins, T. M., and Robertson, J. E. "Pressure Tests on a 0.04-Scale Model of the Saturn V Launch Vehicle at Mach Numbers from 0.60 through 1.45." AEDC-TR-66-217 (AD801520), November 1966.
2. Henson, Victor R. "Static Aerodynamic Characteristics of the Apollo-Saturn V Vehicle." NASA TMX-53307, July 26, 1965.
3. Test Facilities Handbook (6th Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, November 1966.

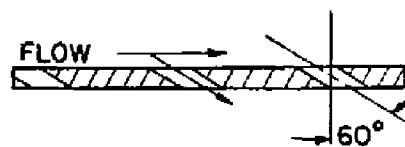
**APPENDIXES**

**I. ILLUSTRATIONS**

**II. TABLE**



TYPICAL PERFORATED WALL PATTERN



Section A-A

6% Open Area  
Hole Diameter = 0.75 In.  
Plate Thickness = 0.75 In

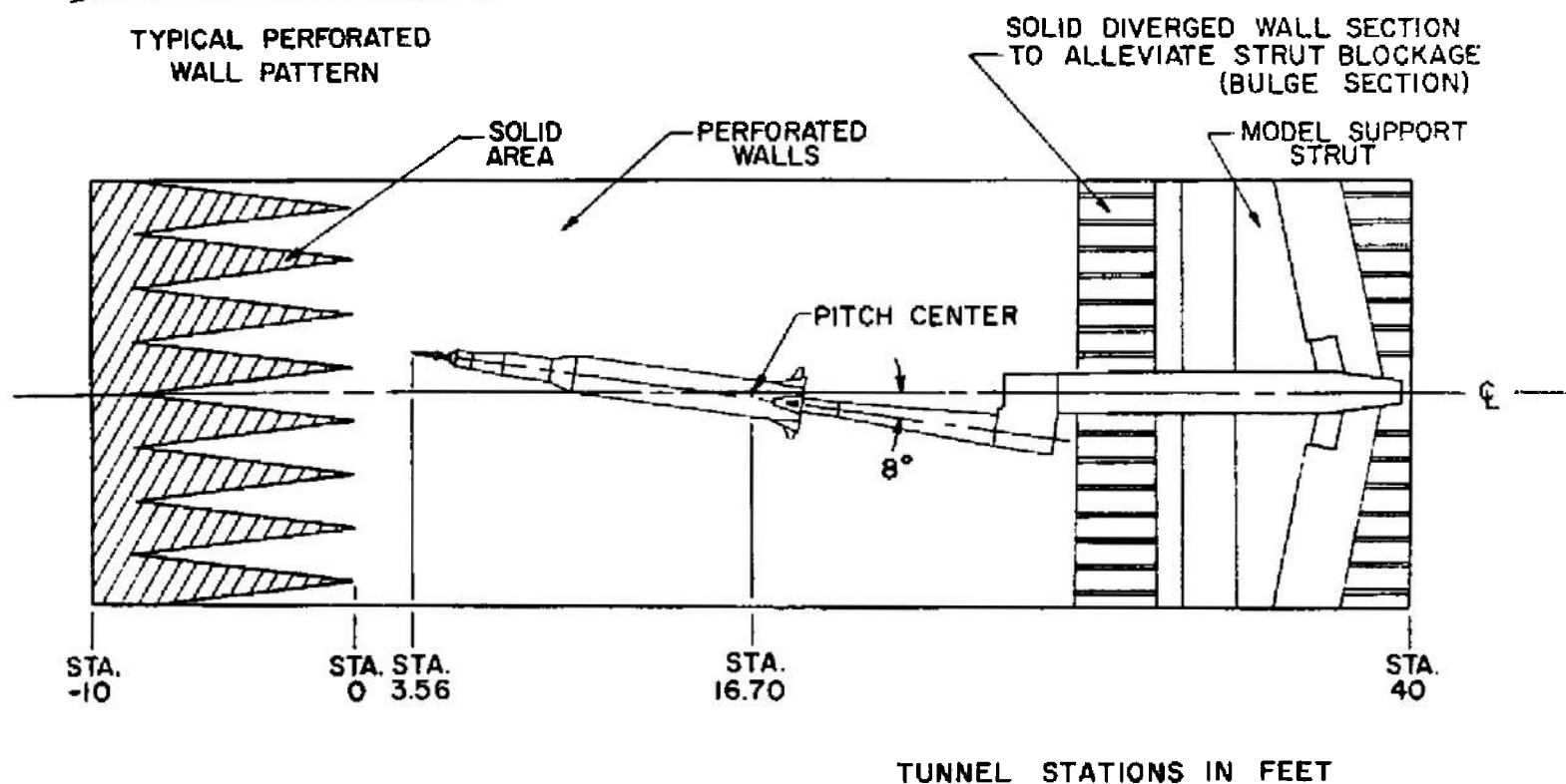


Fig. 1 Schematic of the Saturn V Model Mounted in the 16T Test Section

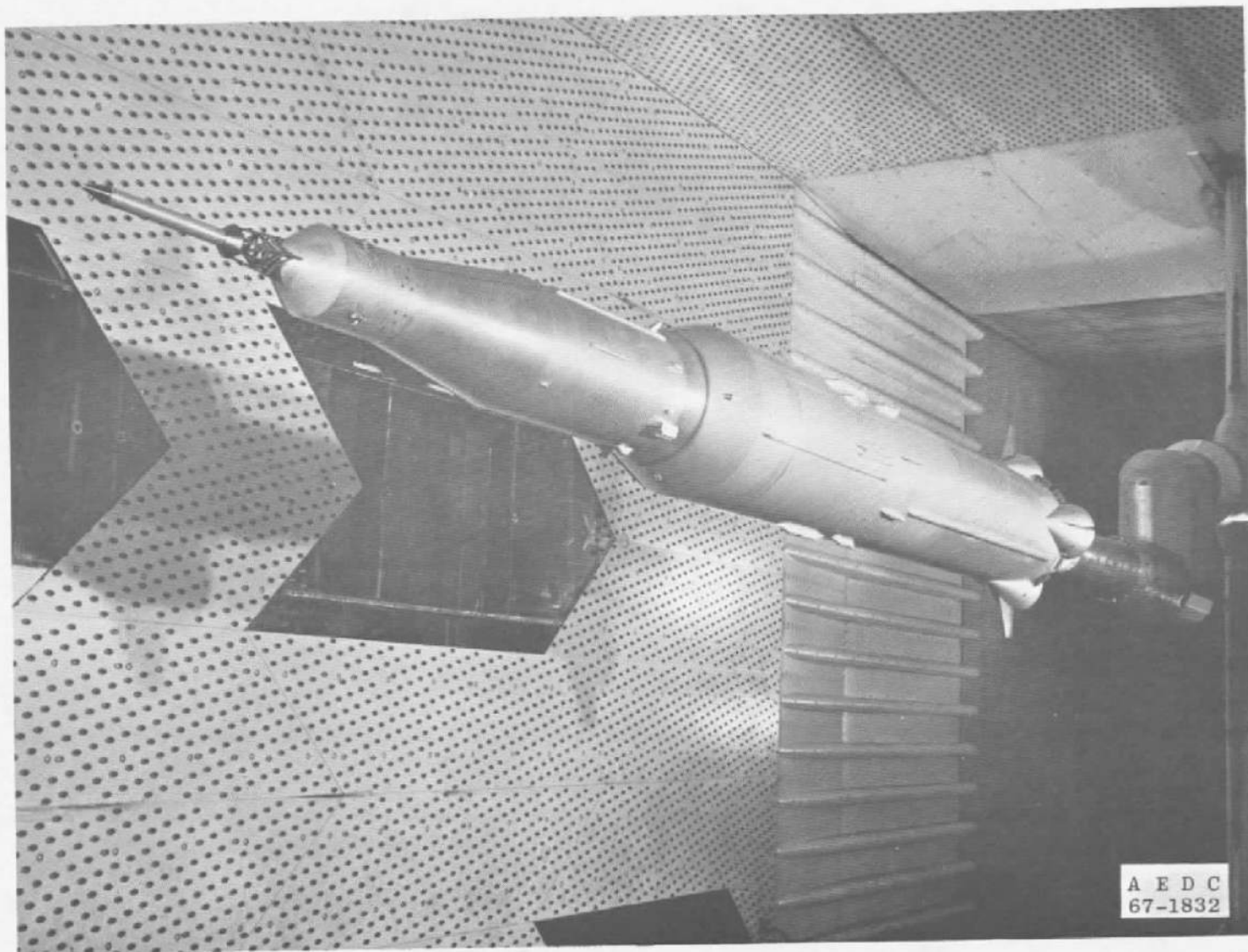
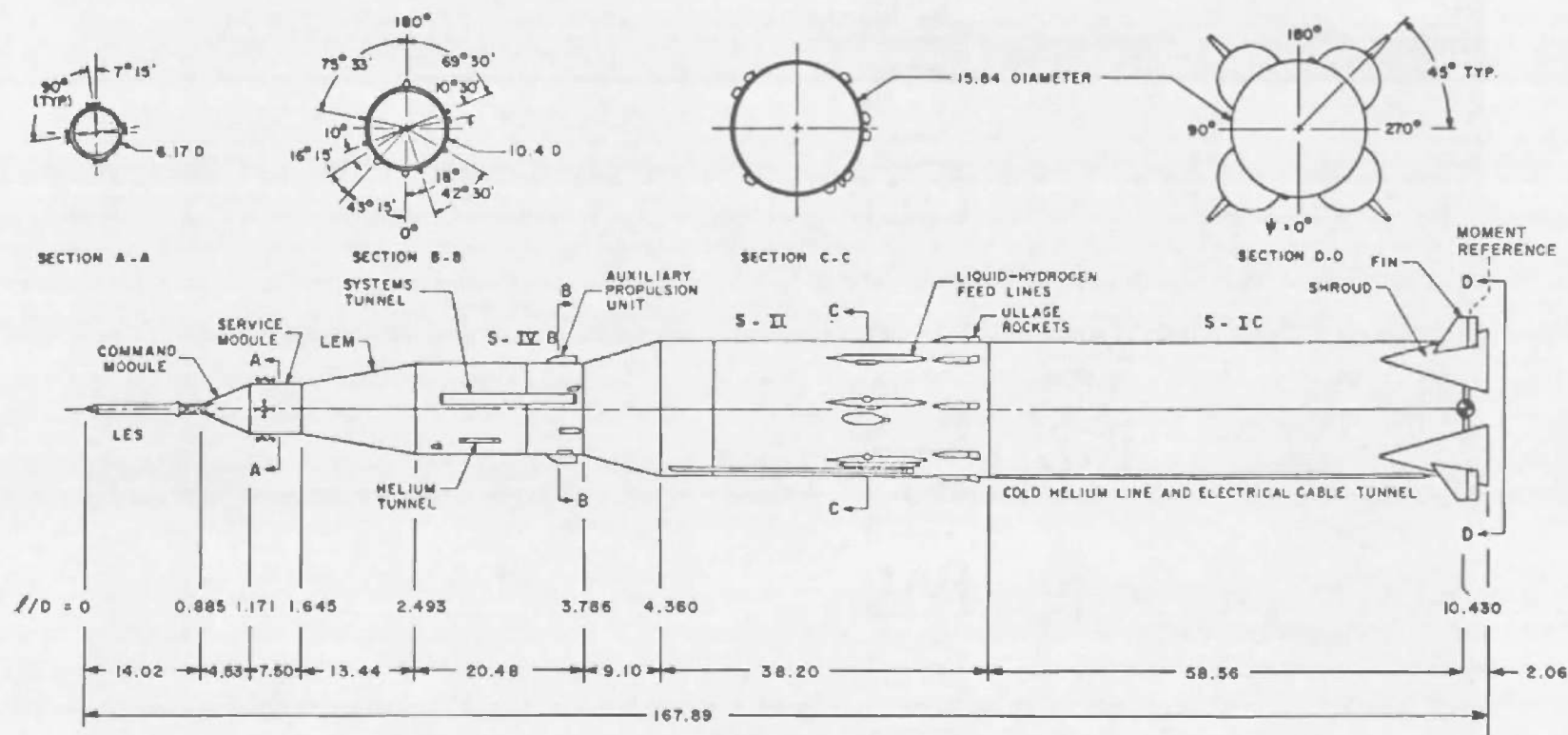


Fig. 2 Photograph of the Model in 16T



NOTE: MODEL AS SHOWN IS ROLLED 45 DEG FROM TUNNEL ORIENTATION.

MOMENT REFERENCE CENTER AT  $R/D = 10.469$

ALL LINEAR DIMENSIONS IN INCHES.

Fig. 3 Details of the Model

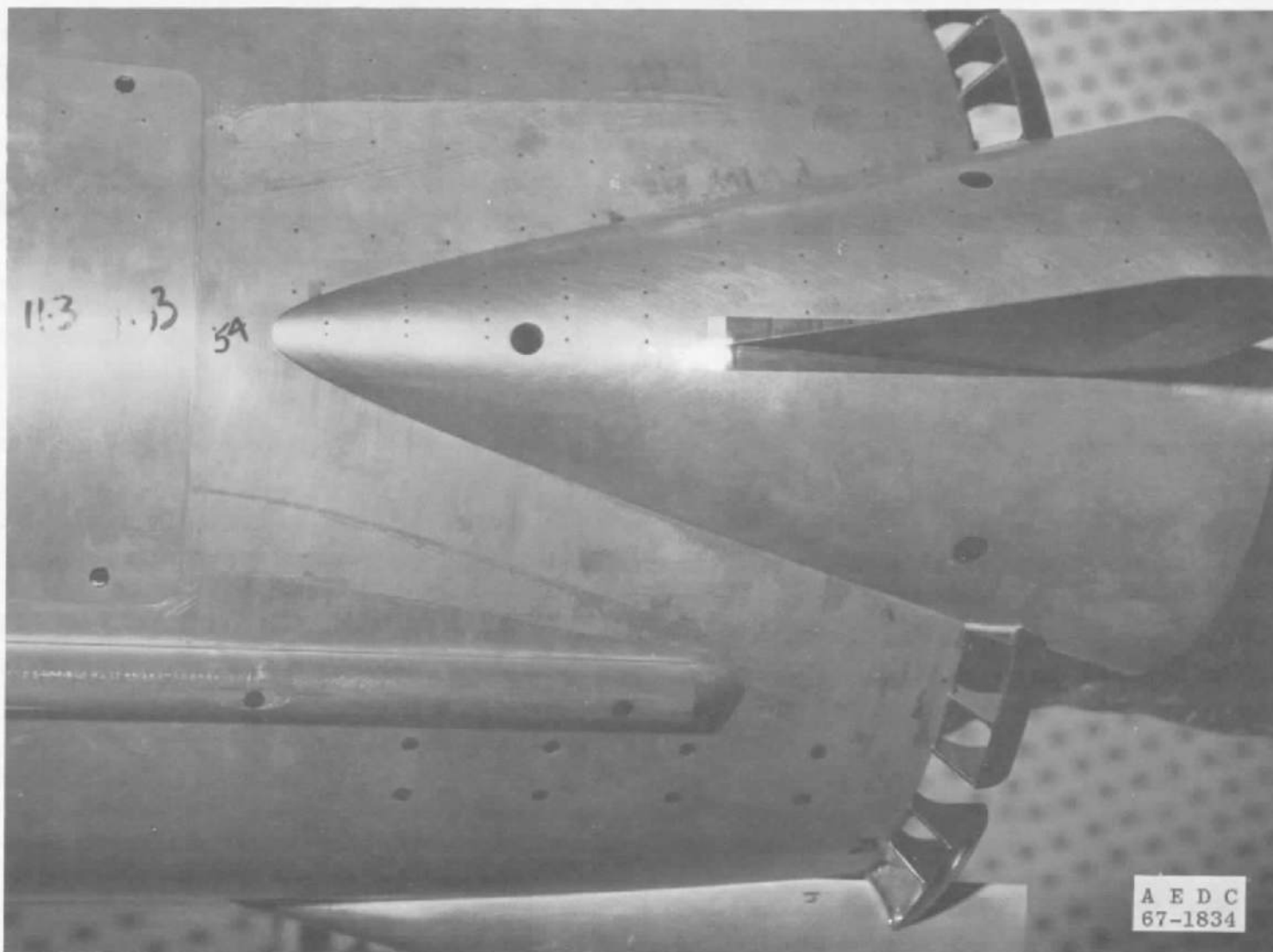


Fig. 4 Photograph of the Static Orifices in the Shroud-Fin Region

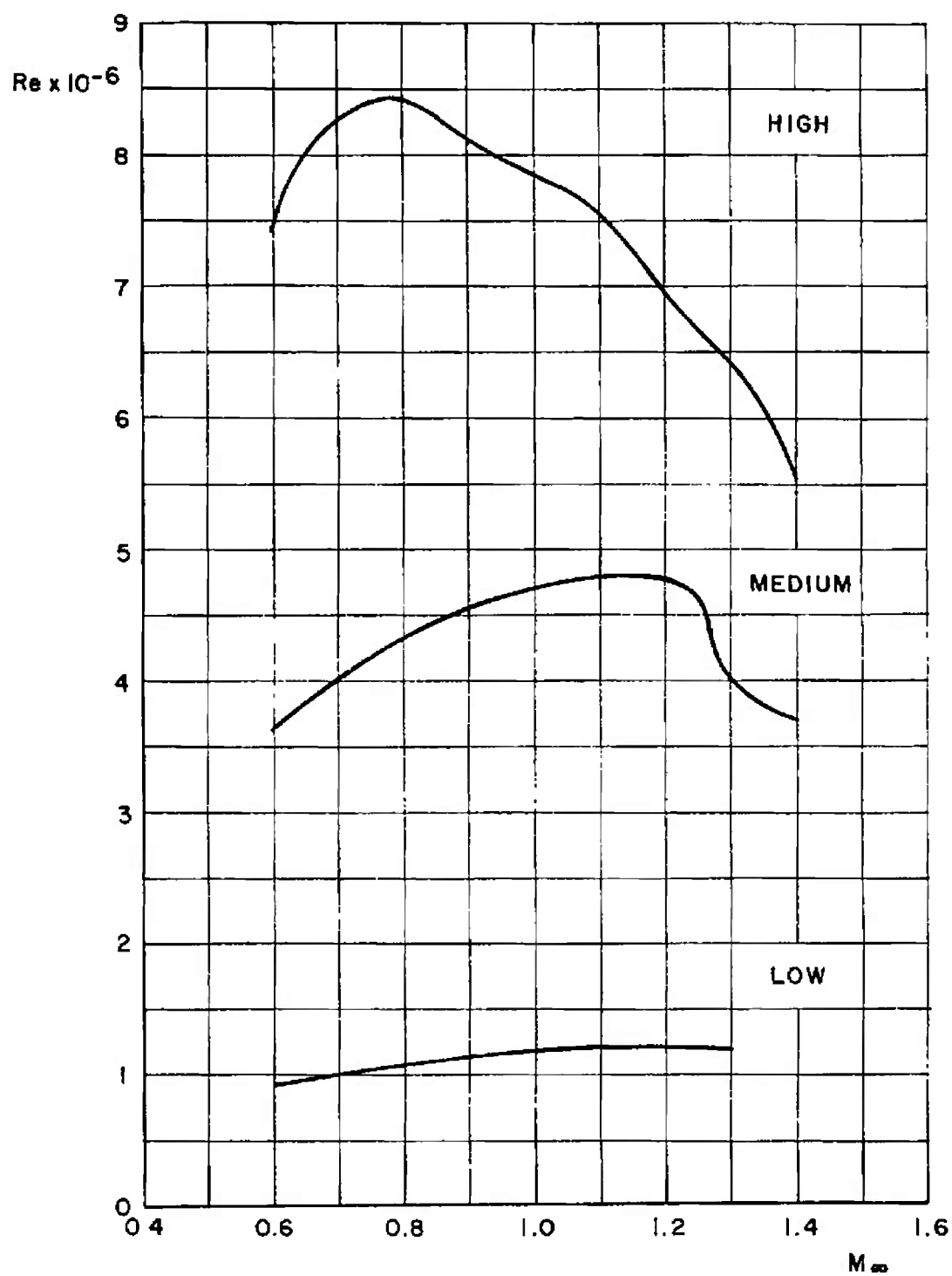


Fig. 5 Variation of Reynolds Number with Mach Number

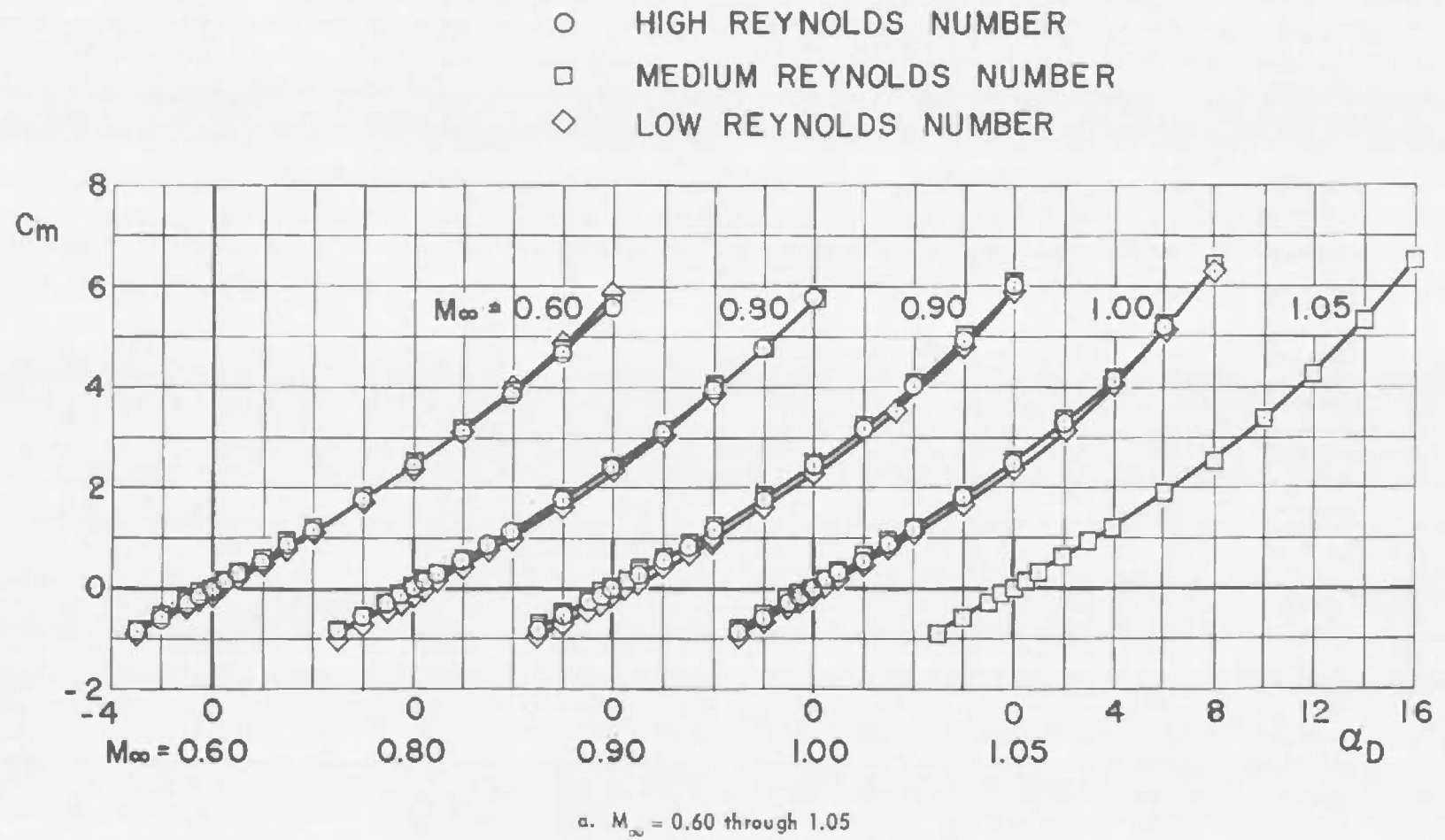
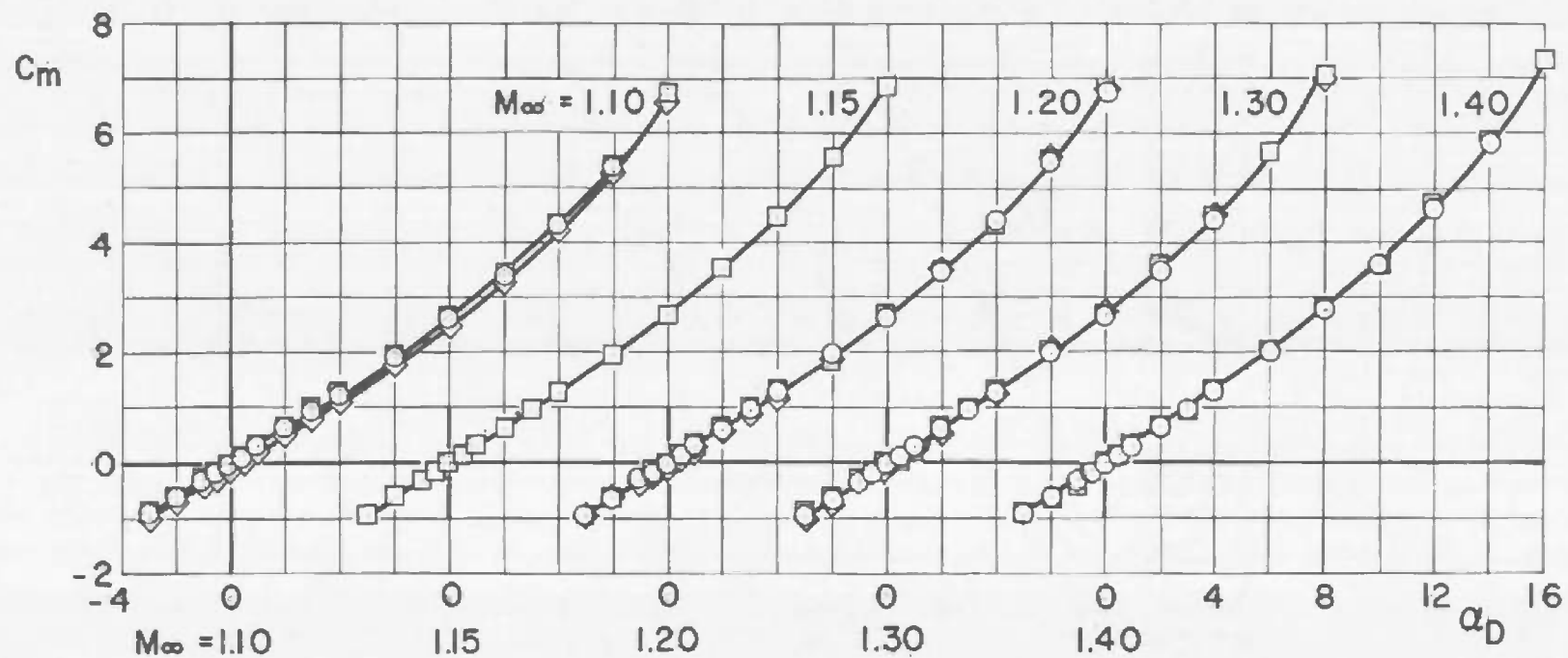


Fig. 6 Variation of Pitching-Moment Coefficient with Angle of Attack

- HIGH REYNOLDS NUMBER
- MEDIUM REYNOLDS NUMBER
- ◇ LOW REYNOLDS NUMBER



b.  $M_\infty = 1.10$  through 1.40

Fig. 6 Concluded

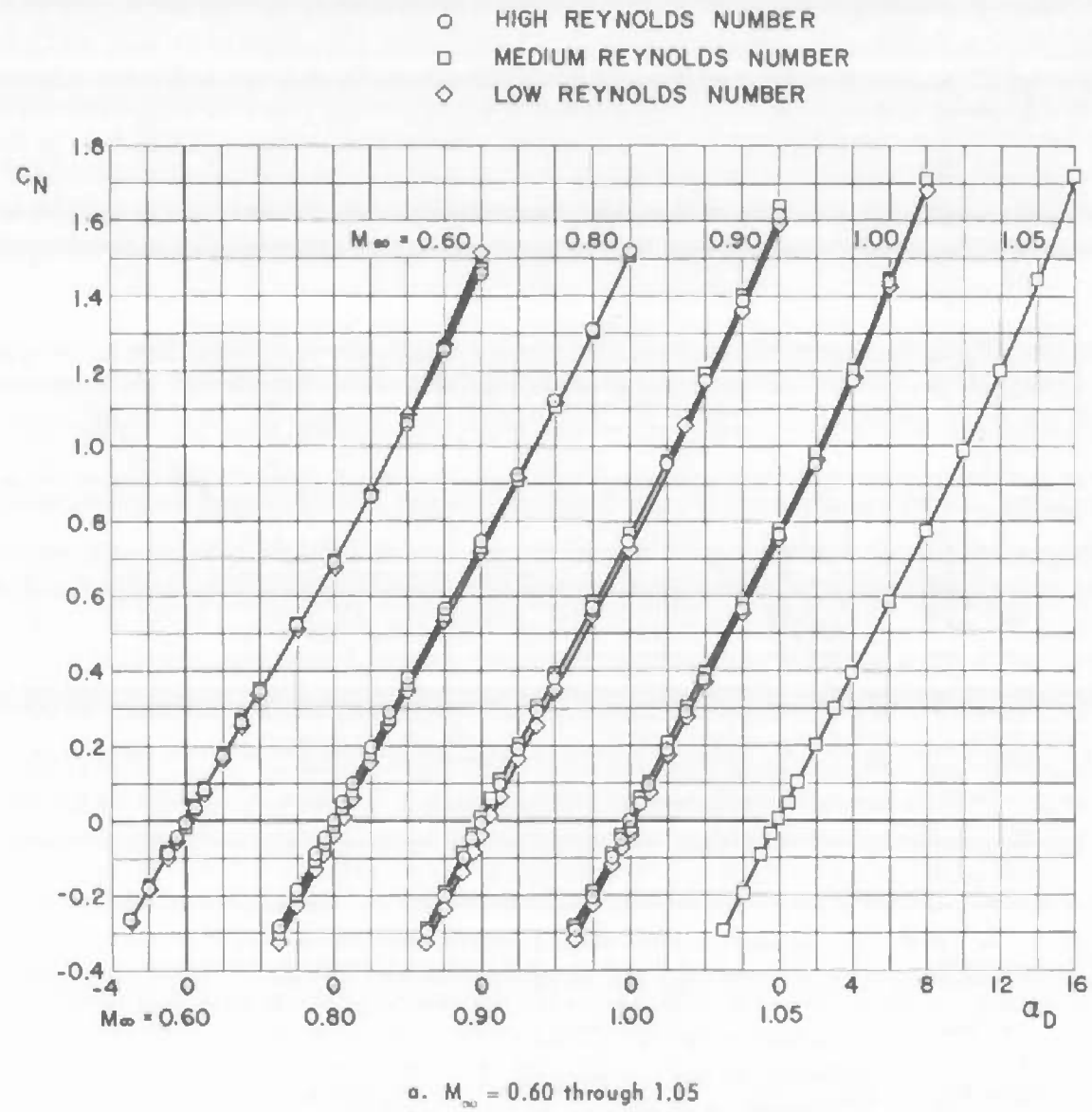


Fig. 7 Variation of Normal-Force Coefficient with Angle of Attack

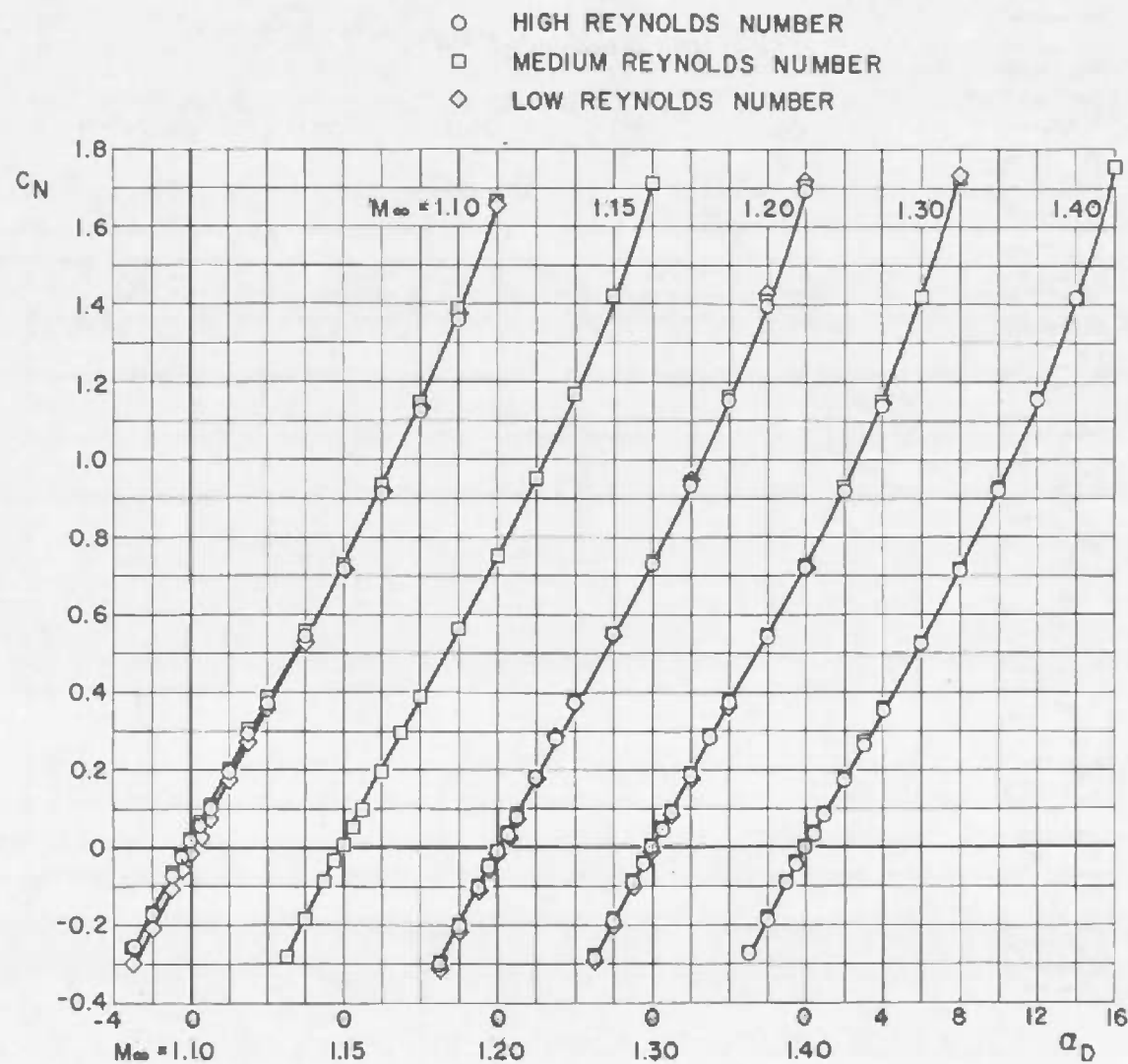
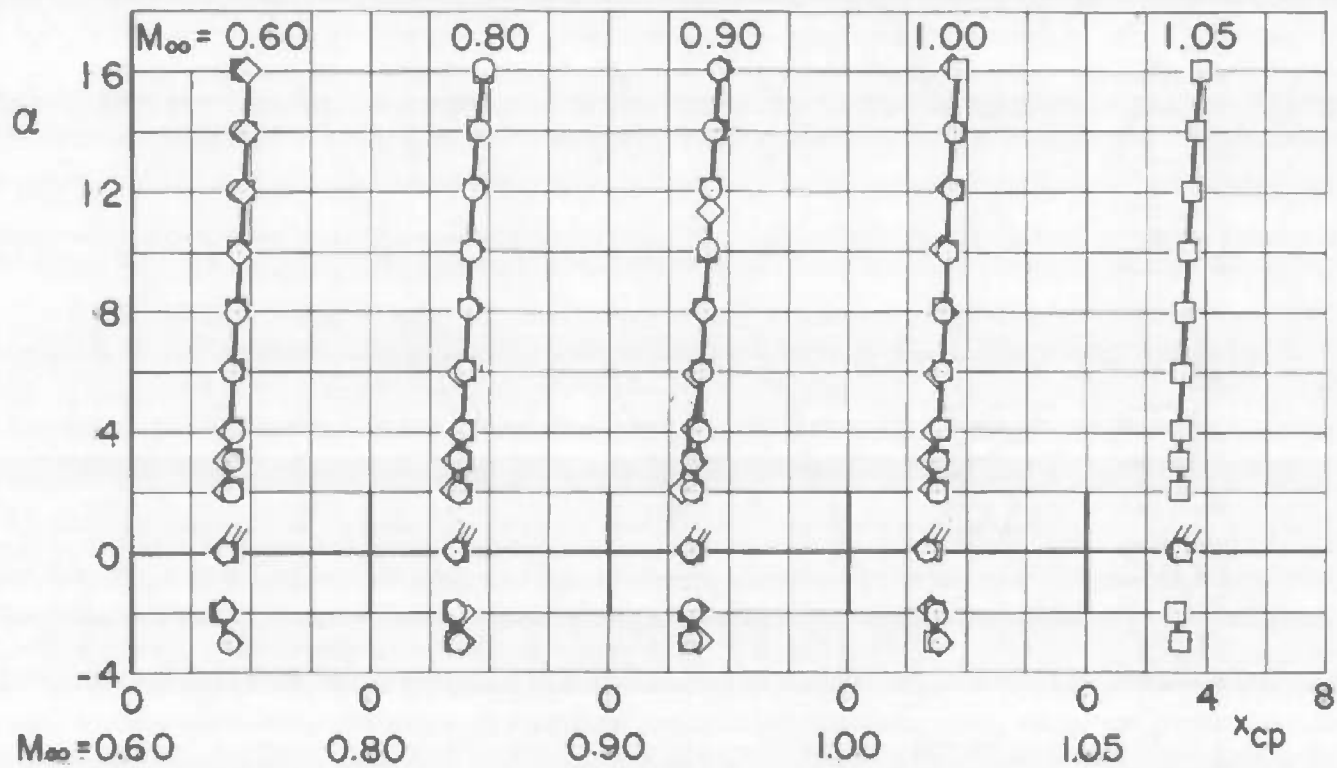
b.  $M_\infty = 1.10$  through 1.40

Fig. 7 Concluded

- HIGH REYNOLDS NUMBER
- MEDIUM REYNOLDS NUMBER
- ◇ LOW REYNOLDS NUMBER

FLAGGED SYMBOLS INDICATE NEUTRAL-POINT LOCATIONS

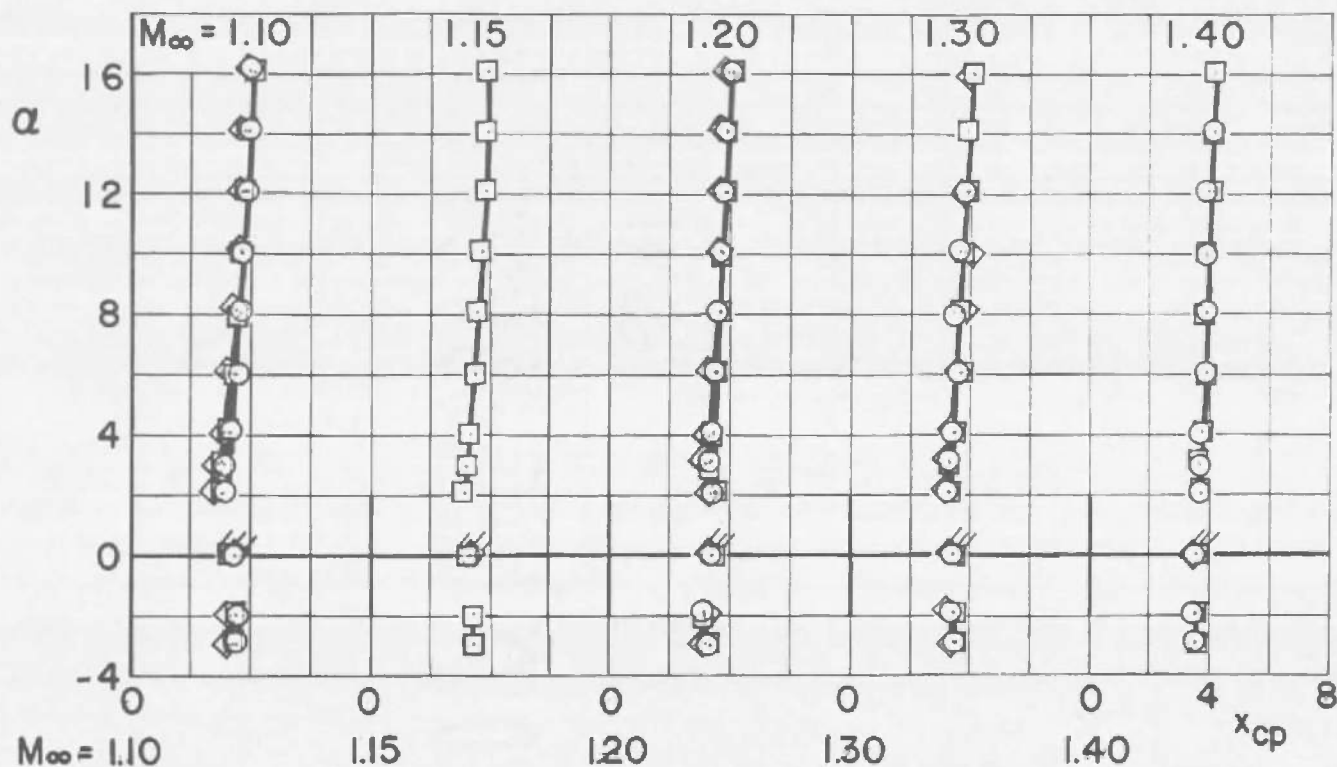


a.  $M_\infty = 0.60$  through 1.05

Fig. 8 Center-of-Pressure Variation with Angle of Attack

- HIGH REYNOLDS NUMBER
- MEDIUM REYNOLDS NUMBER
- ◇ LOW REYNOLDS NUMBER

FLAGGED SYMBOLS INDICATE NEUTRAL-POINT LOCATIONS



b.  $M_\infty = 1.10$  through 1.40

Fig. 8 Concluded

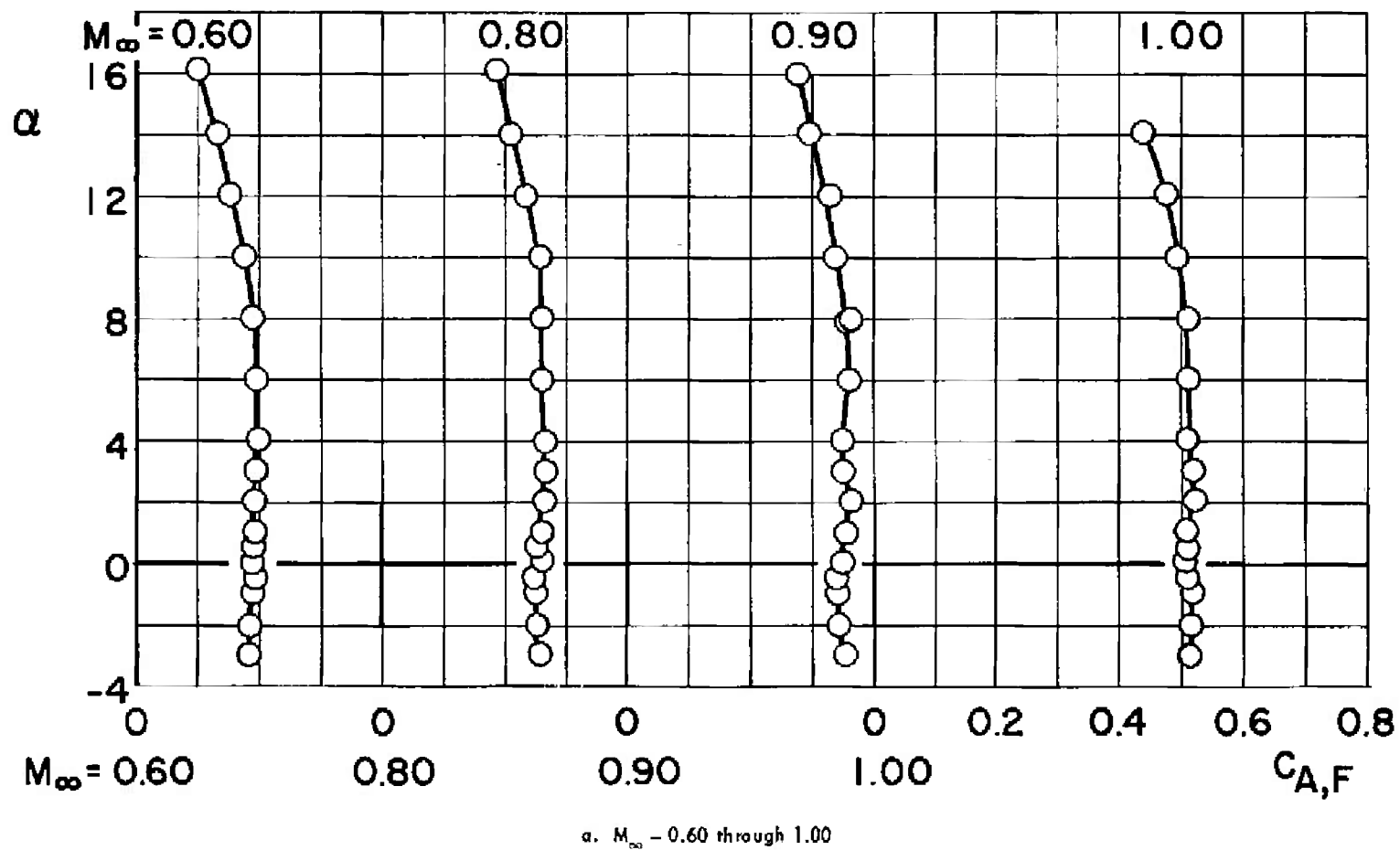
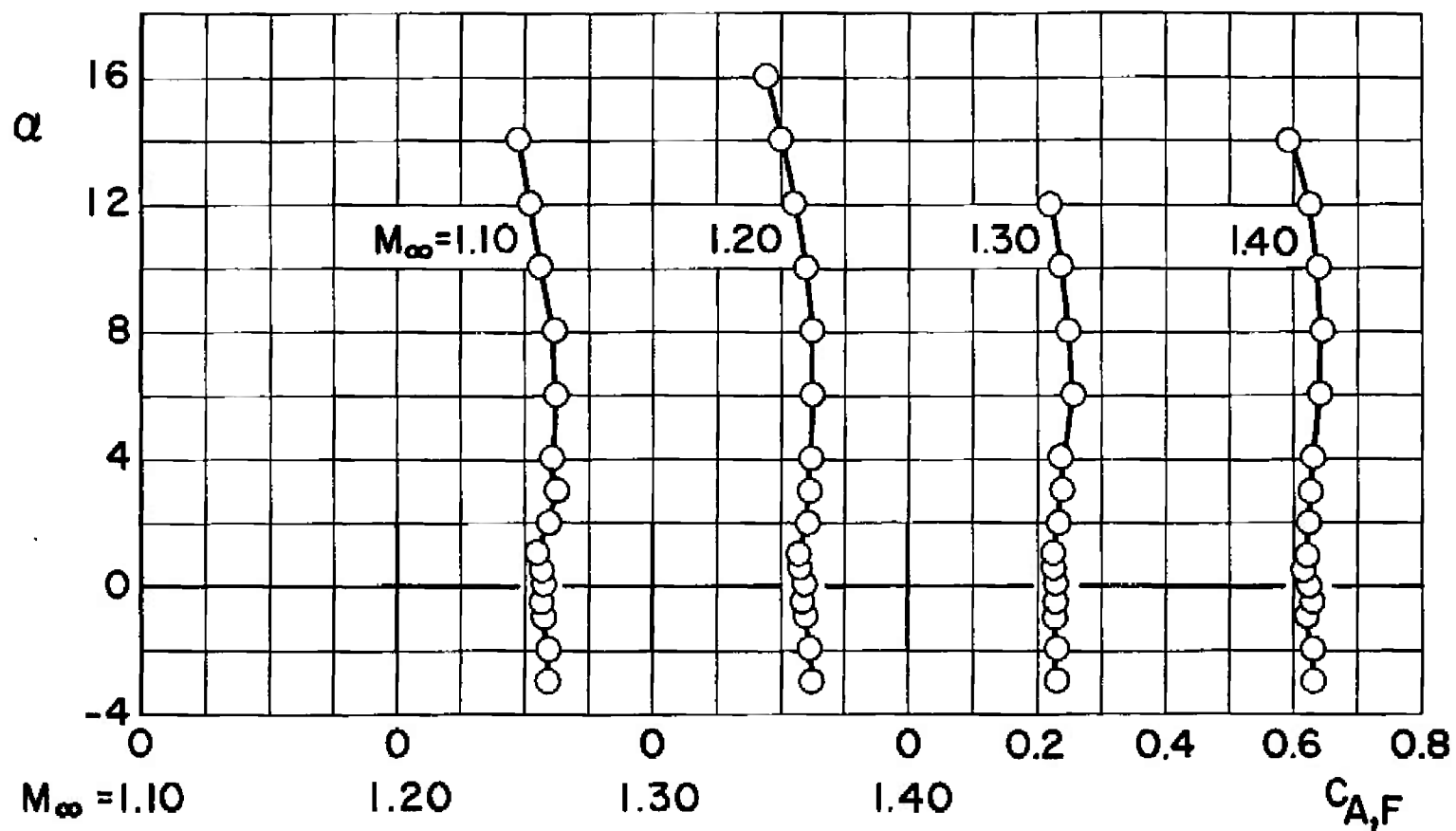


Fig. 9 Variation of Forebody Axial-Force Coefficient with Angle of Attack



b.  $M_{\infty} = 1.10$  through 1.40

Fig. 9 Concluded

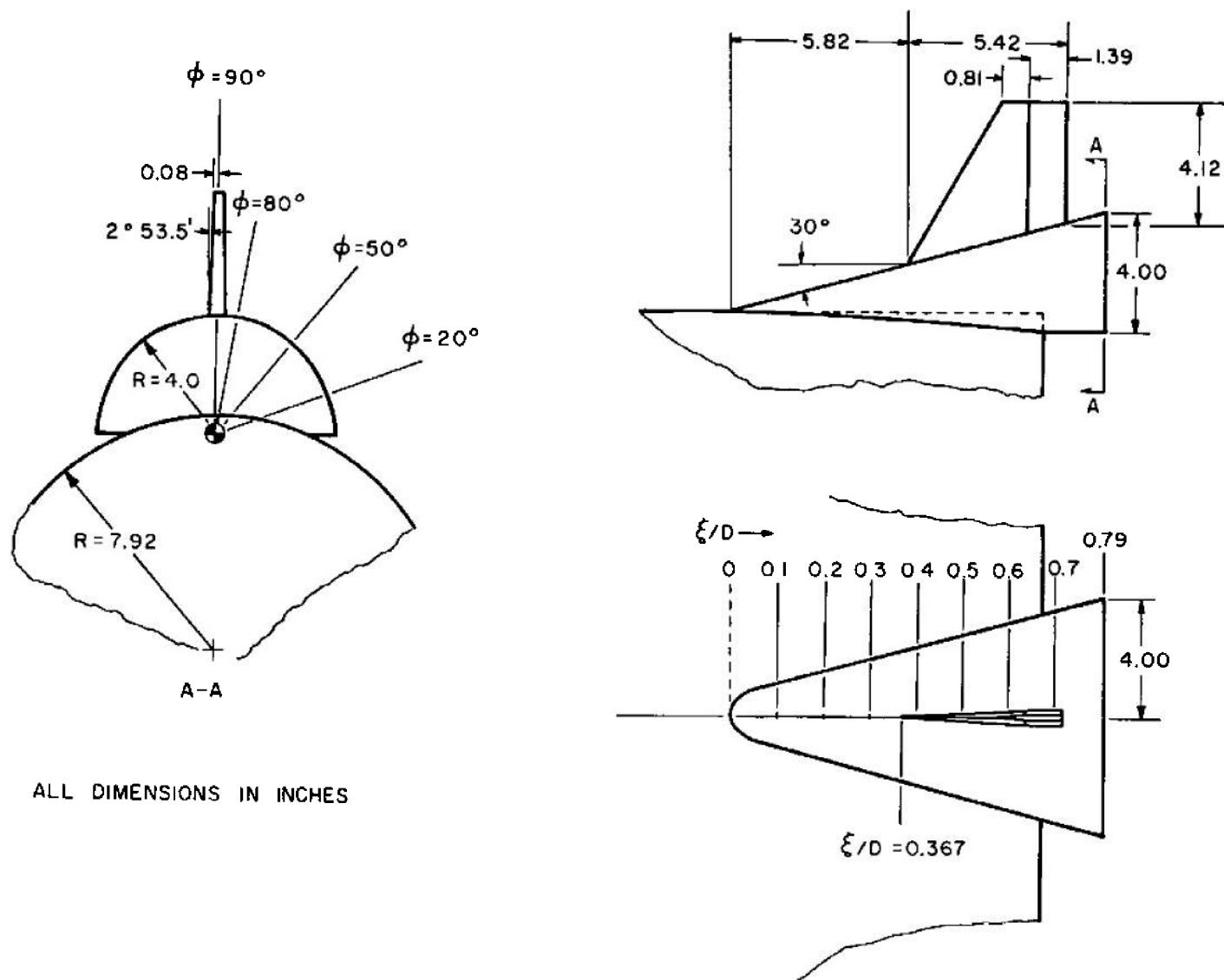


Fig. 10 Shroud-Fin Region Showing the Nomenclature Used in Figs. 11 and 12

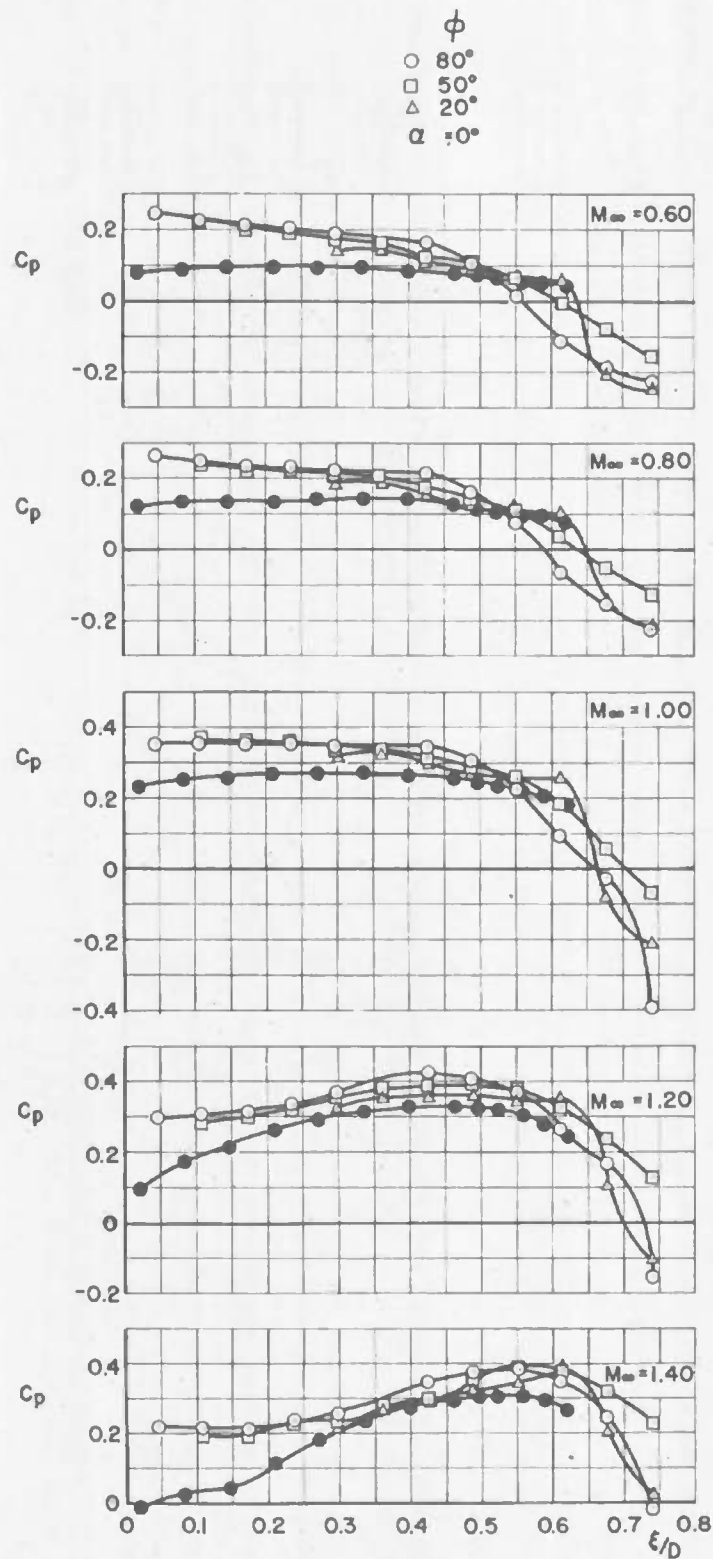


Fig. 11 Longitudinal Variation of Pressure Coefficients along a Shroud and Midway between Two Shrouds, High Reynolds Number

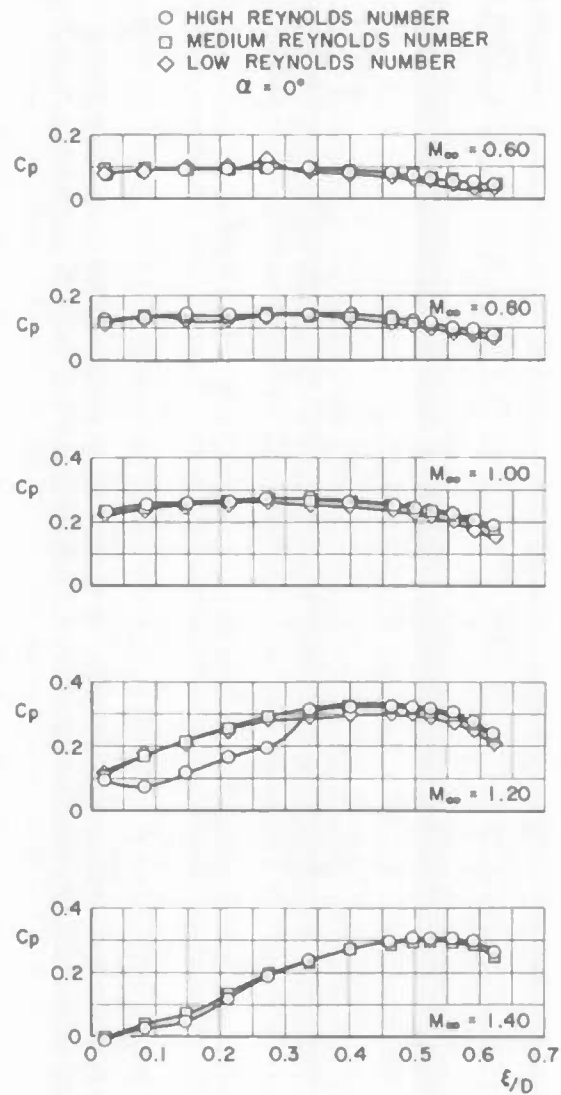


Fig. 12 Reynolds Number Effect on Pressure Coefficients Midway between Two Shrouds

TABLE I  
FORCE COEFFICIENT UNCERTAINTIES

$M_\infty$	Re	$\Delta C_N$	$\Delta C_m$	$\Delta C_A$
0.60	High	0.0058	0.0230	0.0100
0.80		0.0040	0.0170	0.0070
0.90		0.0040	0.0160	0.0070
1.00		0.0040	0.0150	0.0070
1.10		0.0040	0.0150	0.0070
1.20		0.0040	0.0170	0.0070
1.30		0.0040	0.0160	0.0070
1.40		0.0050	0.0190	0.0080
0.60	Medium	0.0120	0.0480	0.0210
0.80		0.0080	0.0320	0.0140
0.90		0.0070	0.0290	0.0120
1.00		0.0070	0.0270	0.0110
1.05		0.0070	0.0260	0.0110
1.10		0.0060	0.0250	0.0110
1.15		0.0060	0.0250	0.0100
1.20		0.0050	0.0240	0.0100
1.30	Low	0.0070	0.0280	0.0120
1.40		0.0090	0.0360	0.0150
0.60		0.0480	0.1920	0.0830
0.80		0.0300	0.1190	0.0560
0.90		0.0290	0.1140	0.0490
1.00		0.0270	0.1050	0.0450
1.10		0.0250	0.0990	0.0420
1.20		0.0240	0.0960	0.0400
1.30		0.0230	0.0940	0.0390

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### KEY WORDS

transonic flow

5 4

**LINK A**

ROLE

WT

LINK 8

ROLE

WT

LINK C

ROLE

W T

--- Saturn V

## Stability

## Pressure Distribution

Transonic flow.

19-4